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TO: 925/Bruce Guenther/MCST

FROM: 925/Edward Knight/MCST

SUBJECT: MODIS Thermal Band Spectral Profiles as a Function of Scan Angle

References:

1. "Scan Angle Dependecne in Infrared Radiometric Calibration," by G. Godden, E, Knight, B. Guenther, in Proceedings of the Fifth SDL/USU Symposium on Infrared Radiometric Sensor Calibration, May 8-11, 1995.

2. "EM Test Data Review Action Items," PL3095-M05068, #2417, by T. Pagano, June 14, 1995.

Introduction

In reference 1, we addressed the variation in the radiometric signal as a function of the MODIS scan angle. During the course of the EM Test Data Review at SBRC, a question arose about possible changes in the spectral profile as a function of scan angle. Reference 2 lists an action item, nominally assigned to me, to "provide a plan to understand and quantify the effect of bands 29, 30, 33-36 spectral response vs scan angle. Quantify uncertainties."

MIT Lincoln Laboratory measured the MODIS scan mirror witness samples and this data was presented in reference 1. The reflectivity was measured for both s and p polarizations for two witness samples, #3 and #4 at 5 different angles of incidence. The average reflectivity is presented in Figure 1. This is an average over the two samples, and an average of s and p polarizations (i.e., average reflectance assuming an unpolarized source).

Figure 1 also includes the modelled mirror spectral profile carried in the SBRC MSAP model. This profile is based on measurements on the TM mirror and was used in all spectral modelling by SBRC or myself to date. This profile was fixed for all scan angles in the infrared. The MSAP model does include scan angle variations in the mirror spectral profile for the reflective bands, but the Lincoln Laboratory measurements do not extend to low enough wavelengths for comparison purposes.

In order to examine the changes in the spectral profiles of the MODIS bands as a function of scan angle, I have modified MSAP to use the Lincoln Laboratory data. This report addresses my changes, the results, and concludes that there is no significant change in spectral response as a function of scan angle.

MSAP modifications

To run the spectral model, I was forced to modify the MSAP source code. Basically, I increased the array dimensions so that MSAP could handle the high resolution Lincoln Laboratory data. While the current Version of MSAP is 2.1, I only have source code for Version 2.0. Hence, I created Version 2.0EK, to distinguish my changes from those implemented by SBRC. This version was checked against 2.1, and generates equal results for equal input files. Note that the Lincoln Laboratory data only extends from 2.5 to 14.2 micrometers. For the reflective bands, we must still rely on the modelled data. For Bands 35 and 36, (where the profiles extends beyond 14.2 μm), the mirror data are linearly extrapolated. The routine to do this will introduce additional errors into these bands.

In addition to using the Lincoln Laboratory mirror data, I am using the current best predictions for the LWIR filters. As many may recall, the Protoflight Model PFM mask was recently damaged, resulting in a last minute change in the filters being used. I am using the filter data corresponding to the serial numbers informally provided by Tom Pagano on July 13. I am also still using the modelled LWIR mask data, since the actual mask is currently undergoing measurement. There is a very good chance that the actual LWIR mask will differ from the model enough to affect Bands 27 and 31, as was observed with the damaged mask. I intend to review all these data with Tom Kampe soon. As a consequence, <u>all values quoted for Center Wavelengths and Bandwidths should be considered preliminary</u>.

Individuals should continue to be referred to me or John Barker for the most recent "best" predictions, and we still expect to release the definitive spectral data set after PFM system level testing.

Results

Tables 1 and 2 present the calculated center wavelengths and bandwidths from using the actual mirror data in the spectral model. These system level predictions are compared with the "Modelled Mirror" that has been used in MSAP in the past. Also included are data for a "Perfect Mirror" which is the system level result with the mirror reflectance set to 1.0 for all wavelengths and polarizations. The "Perfect Mirror" results are thus equivalent to the system level predictions that include all components except the mirror.

As can be seen, there is no significant variation in center wavelength or bandwidth. All variations that do occur are less than 1 nm, which is less than the uncertainty of the mirror measurements in this spectral region.

This result is because the spectral variation of the mirror occur very gradually over the bandwidth of the filter. Figure 2 superimposes the "Perfect Mirror" results with the mirror data. The lefthand scale gives the reflectance of the mirror and the righthand scale gives the system level transmittance of the MODIS as if the scan mirror were perfect. The scales have different ranges but the same increment so that they might be easily compared. As can be seen, the steepest variation in the mirror data, about a 10% change in reflectance, occurs between bands at about 8.3 micrometers. In all other regions, the overall reflectance varies, but the slopes are very comparable.

Figures 3 through 5 also show how the slopes between the different mirror angles of incidence are very close. The mirrors are essentially flat across the widths of Bands 29, 30, and 33-36, which are expected to be the most dramatically affected by the mirror spectral profile. Table 3 gives the slope across the bandwidth for these bands. These slopes are based on a linear interpolation between the mirror reflectance values at the band edges. As can be seen, there is only a small variation in the slope across the entire band as a function of scan angle. Table 3 also includes a rough estimate of the threshold required for a linear slope change to affect the center wavelength (calculation of this threshold is discussed in the appendix). The variation is an order of magnitude below the calculated threshold necessary to observe a change in the center wavelength.

Conclusion

Based upon the lack of change in the center wavelengths and bandwidths in the spectral model, calculated for mirror angles of incidence from 19 degrees to 65 degrees, it is clear that there is no significant change in the spectral response as a function of scan angle.

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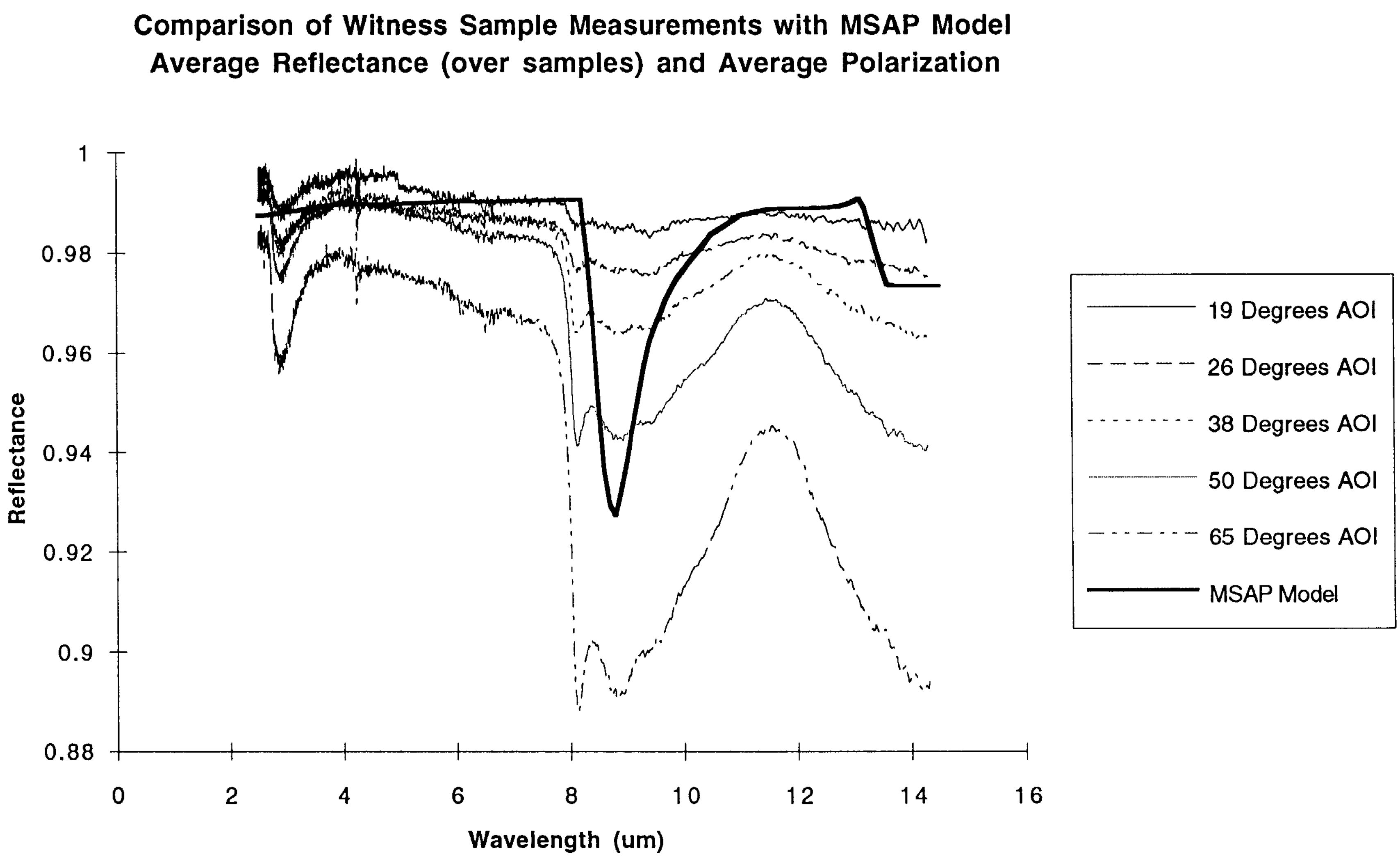
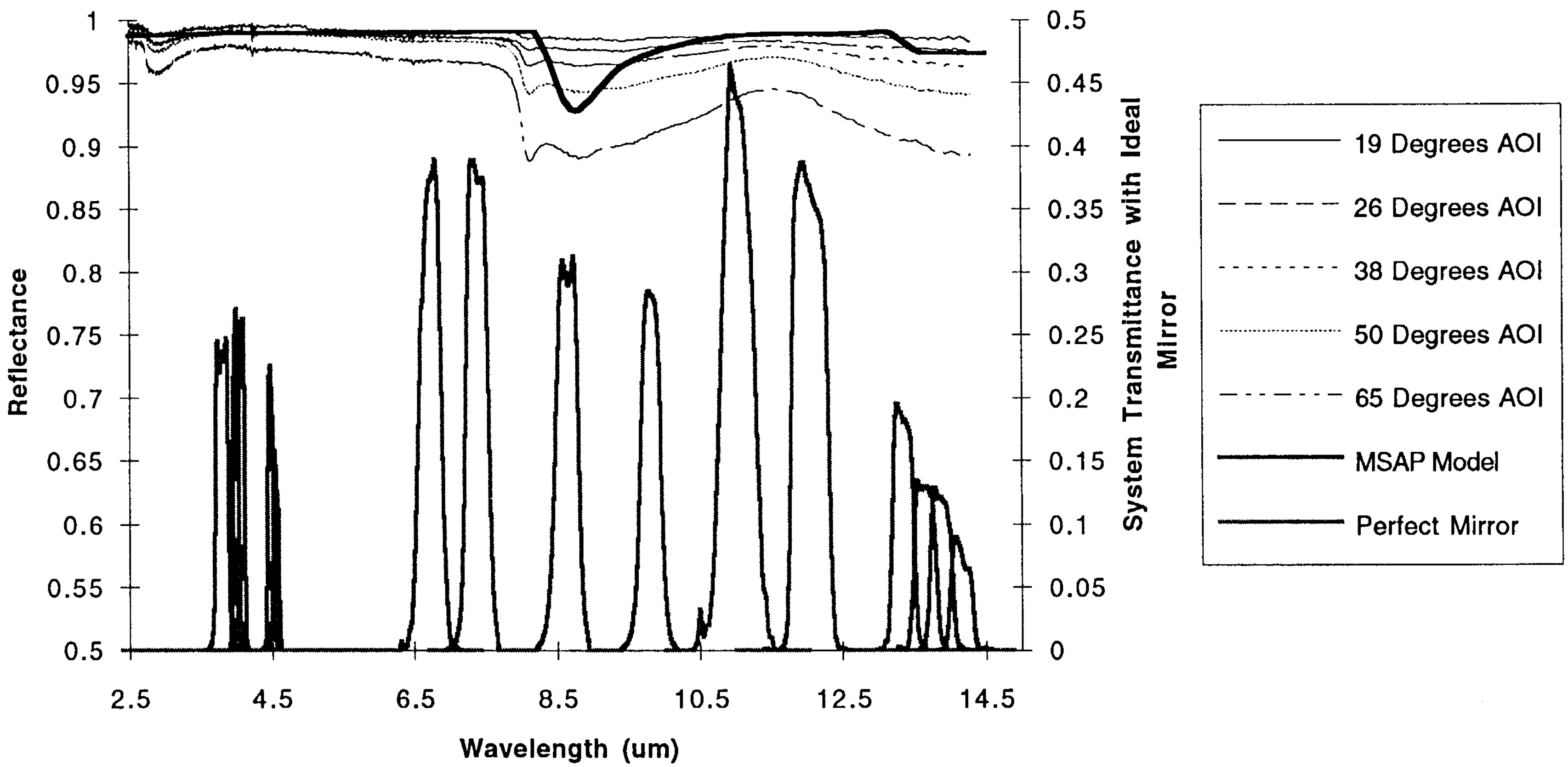
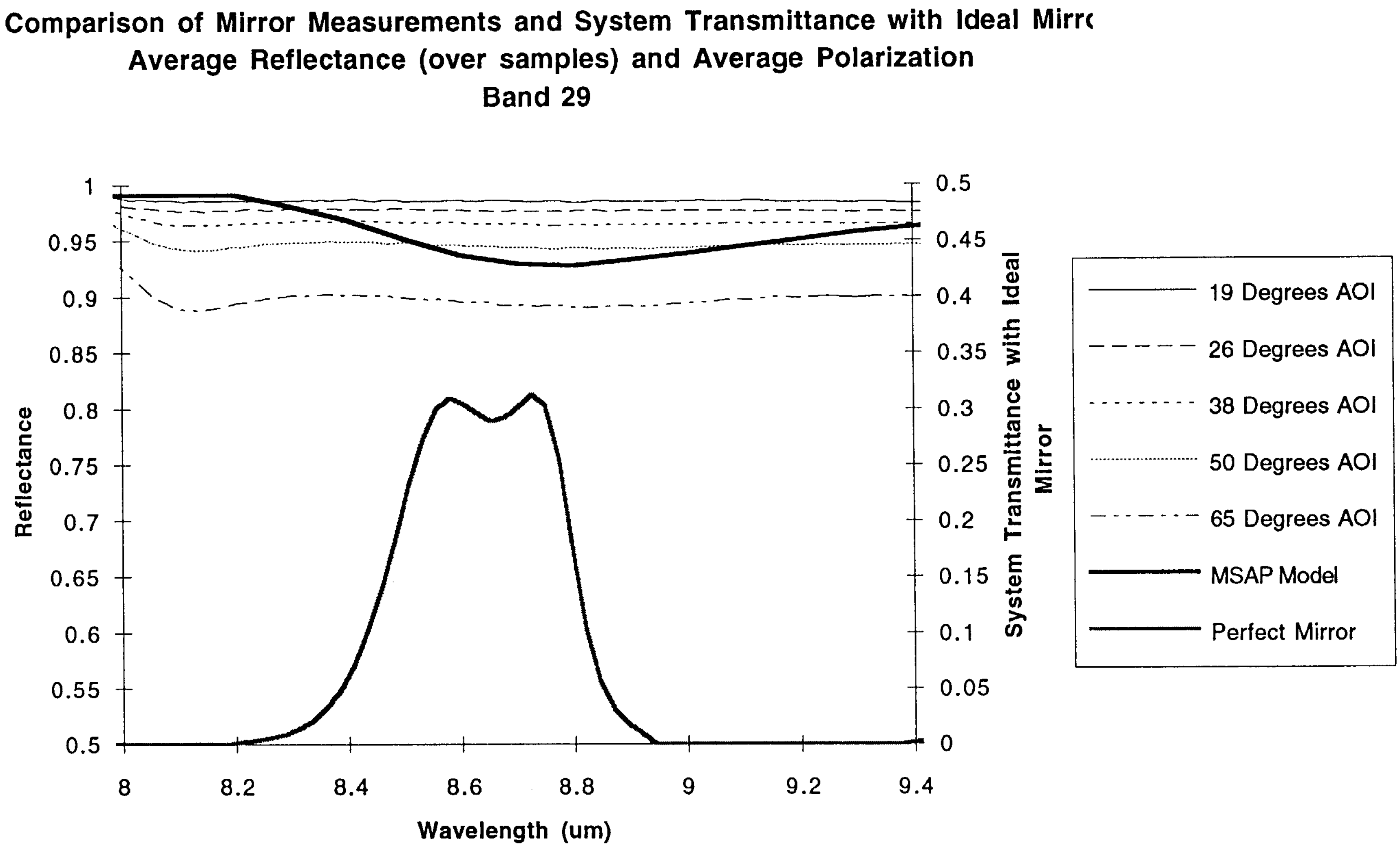

Comparison of Witness Sample Measurements with MSAP Model
Average Reflectance (over samples) and Average Polarization
Reflectance
1
0.98
0.96
0.94
0.92
0.9
0.88
0
2
4
6
8
10
12
14
16
Wavelength (um)
19 Degrees AOI
26 Degrees AOI
38 Degrees AOI
50 Degrees AOI
65 Degrees AOI
MSAP Model

Center Wavelength and Bandwidth as a function of Scan Angle							
	Center Wavelengths		in micrometers				
	Modelled	Measured					Perfect
Band	Mirror	19 AOI	26 AOI	38 AOI	50 AOI	65 AOI	Mirror
20	3.7954	3.7954	3.7954	3.7954	3.7954	3.7954	3.7954
21	4.0006	4.0006	4.0005	4.0005	4.0005	4.0005	4.0006
22	3.9888	3.9888	3.9889	3.9889	3.9888	3.9888	3.9888
23	4.0749	4.0749	4.0749	4.0749	4.0749	4.0749	4.0749
24	4.4794	4.4794	4.4794	4.4794	4.4794	4.4794	4.4794
25	4.5510	4.5510	4.5510	4.5510	4.5510	4.5510	4.5510
27	6.7283	6.7283	6.7282	6.7282	6.7283	6.7282	6.7283
28	7.3845	7.3845	7.3845	7.3844	7.3844	7.3844	7.3845
29	8.6340	8.6352	8.6352	8.6352	8.6351	8.6348	8.6353
30	9.8112	9.8110	9.8110	9.8111	9.8111	9.8112	9.8110
31	11.0357	11.0357	11.0357	11.0358	11.0359	11.0363	11.0356
32	12.0439	12.0439	12.0439	12.0438	12.0437	12.0435	12.0439
33	13.3358	13.3360	13.3360	13.3360	13.3360	13.3359	13.3360
34	13.6418	13.6419	13.6419	13.6419	13.6418	13.6417	13.6419
35	13.8716	13.8716	13.8715	13.8715	13.8715	13.8715	13.8716
36	14.1570	14.1569	14.1570	14.1570	14.1571	14.1569	14.1570
model uncertainty is about 0.01 micrometers							

	Bandwidths		in micrometers				
	Modelled	Measured					Perfect
Band	Mirror	19 AOI	26 AOI	38 AOI	50 AOI	65 AOI	Mirror
20	0.1876	0.1876	0.1876	0.1876	0.1876	0.1876	0.1876
21	0.0795	0.0795	0.0795	0.0796	0.0795	0.0795	0.0795
22	0.0818	0.0818	0.0818	0.0818	0.0818	0.0818	0.0818
23	0.0840	0.0841	0.0840	0.0840	0.0840	0.0841	0.0840
24	0.0866	0.0865	0.0866	0.0865	0.0866	0.0865	0.0866
25	0.0887	0.0887	0.0887	0.0887	0.0887	0.0887	0.0887
27	0.3211	0.3212	0.3213	0.3210	0.3209	0.3211	0.3211
28	0.3243	0.3244	0.3242	0.3243	0.3243	0.3242	0.3243
29	0.3373	0.3351	0.3351	0.3352	0.3353	0.3358	0.3350
30	0.3005	0.3005	0.3006	0.3006	0.3005	0.3006	0.3006
31	0.4771	0.4773	0.4773	0.4773	0.4772	0.4775	0.4772
32	0.5129	0.5129	0.5128	0.5127	0.5126	0.5122	0.5129
33	0.3015	0.3019	0.3018	0.3019	0.3018	0.3018	0.3019
34	0.3246	0.3248	0.3246	0.3247	0.3247	0.3242	0.3247
35	0.3143	0.3143	0.3143	0.3142	0.3143	0.3143	0.3143
36	0.3093	0.3091	0.3092	0.3093	0.3094	0.3091	0.3093
model uncertainty is about 0.01 micrometers							

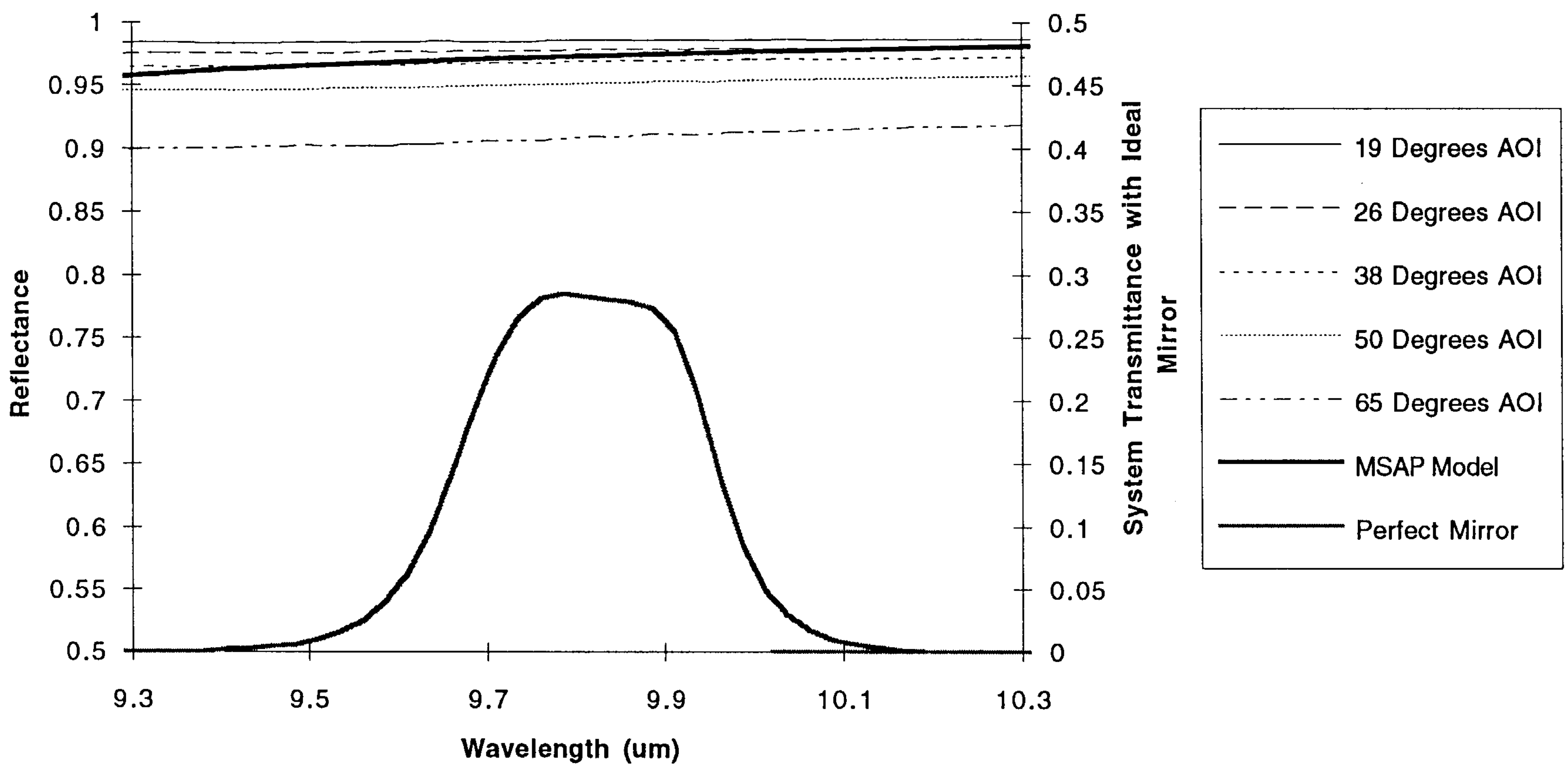
Comparison of Mirror Measurements and System Transmittance with Ideal Mirr(
Average Reflectance (over samples) and Average Polarization



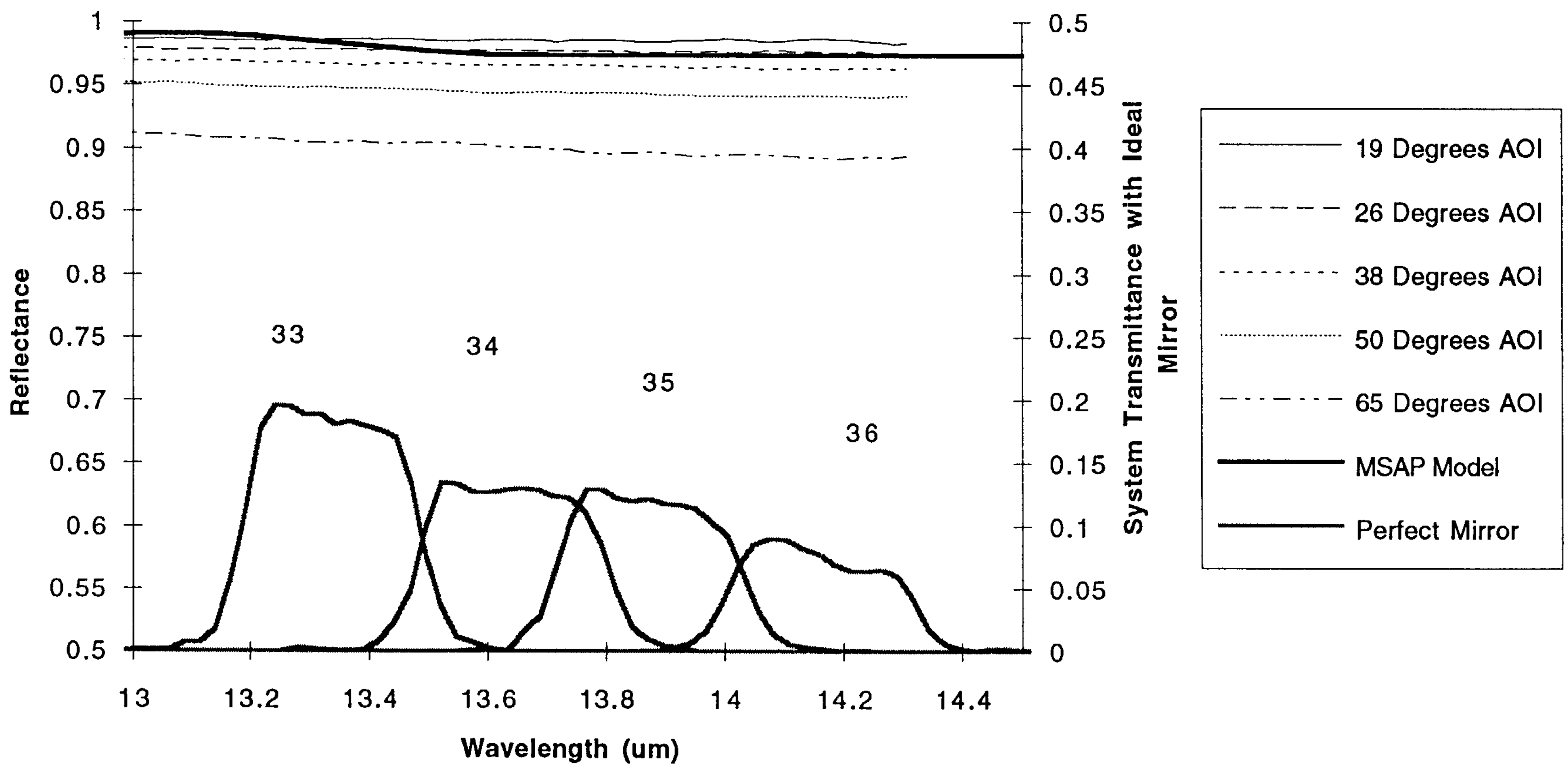


Comparison of Mirror Measurements and System Transmittance with Ideal Mirr
Average Reflectance (over samples) and Average Polarization
Band 29
Reflectance
System Transmittance with Ideal Mirror
Wavelength (um)
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0.55
0.5
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
8
8.2
8.4
8.6
8.8
9
9.2
9.4
19 Degrees AOI
26 Degrees AOI
38 Degrees AOI
50 Degrees AOI
65 Degrees AOI
MSAP Model
Perfect Mirror

Comparison of Mirror Measurements and System Transmittance with Ideal Mirr(
Average Reflectance (over samples) and Average Polarization
Band 30



Comparison of Mirror Measurements and System Transmittance with Ideal Mirr(
Average Reflectance (over samples) and Average Polarization
Bands 33-36



SLOPES	units are Reflectance per micrometer							
Computed by linearly connecting mirror reflectance values at band edges								
		Measured Data						Change
Band	MSAP Model	AOI in degrees					Change in	Threshold
	Mirror	19	26	38	50	65	Slope	Magnitude
29	-0.1018	-0.0035	-0.0044	-0.0070	-0.0103	-0.0216	-0.0181	0.7253
30	0.0209	0.0024	0.0088	0.0106	0.0126	0.0253	0.0228	1.0056
33	-0.0410	0.0019	-0.0022	-0.0057	-0.0087	-0.0131	-0.0150	0.6249
34	-0.0108	0.0009	-0.0030	-0.0048	-0.0084	-0.0251	-0.0260	0.4747
35	0.0000	0.0057	-0.0045	-0.0036	-0.0087	-0.0103	-0.0160	0.4873
36	0.0000	-0.0129	-0.0020	-0.0045	-0.0018	-0.0027	0.0102	0.3327

APPENDIX

Slope Threshold Calculation

This calculation addresses a change in the linear slope of an element that forms part of the spectral response of an instrument. As indicated in Figures 2 through 5, no significant structure is introduced in the MODIS thermal bandwidths, but a change in overall linear slope is observed.

The calculated change threshold given in Table 3 comes from a calculation based on a slope change in an idealized rectangular Bandpass. Figure 6 depicts this ideal filter. I assume that the overall offset in reflectance can be normalized to a single wavelength in the bandpass. Figure 6 uses the lower band edge (50% peak response point) as this 'constant' (normalized) point. The change in slope then functions as a lever arm to raise (or lower) the "peak" response. It also shifts the location of the "peak" response. Under current specification definitions, the center wavelength is defined as the midpoint between the 50% response points. Thus, any change in the location or height of the "peak" response can lead to a center wavelength or bandwidth change by changing the location of one of the 50% points.

The idealized rectangular bandpass was chosen because it maximizes the apparent lever arm of a slope change. As shown, any change in slope shifts the peak response from the center of the bandwidth to the band edge opposite the normalization point. Similarly, the normalization point was placed at one band edge to maximize the effect. For realistic filter bandpasses, the effect of slope changes should not be so dramatic.

The new peak response is $Y+\Delta Y$. When this is greater than 2^*Y, then the 50% point will move from the original lower band edge onto the sloped roof of the bandpass. Thus, the threshold condition for a rectangular bandpass is:

$$Y + \Delta Y \geq 2Y . \tag{1}$$

Since I have assumed normalization at the bandedge, the change in slope ΔS is directly related to Δs by:

$$\Delta Y = \Delta S * X. \tag{2}$$

From this, the threshold for change is:

$$\Delta S \geq Y / X. \tag{3}$$

The bandwidths for the filters, X, was used and Y was taken to be the 0.3 for Bands 29 and 30, 0.2 for Band 33, 0.15 for Bands 34 and 35, and 0.1 for Band 36 (rough estimate of total inband transmittance).

Idealized Square Bandpass Suffering a Slope Change